yperopic excimer laser refractive surgery involves the ablation of peripheral cornea to increase the curvature of the center. However, this abrupt increase in corneal curvature from the periphery to the center may result in complications. Despite several technical recommendations that have been proposed to prevent complications, the development of a whitish corneal apical scar may still be observed, especially after high hyperopic corrections, if not properly done. This corneal scar always occurs beneath the epithelium after excimer laser surface ablation regardless of whether the ablation is done under a flap (LASIK) or directly under the epithelium (surface ablation such as photorefractive keratectomy [PRK]). It is always associated with high eccentricity values (e) and corresponds to the point of maximum corneal curvature gradient and steepening. The scar often occurs within the first year after surgery and invariably hampers visual acuity. The etiology of this scar remains controversial, and the most convincing hypothesis comes from the observation of corneal ectasia.

ABSTRACT

PURPOSE: To evaluate long-term results of sequential customized therapeutic keratectomy (SCTK) in highly aberrated corneas with apical scars consequent to hyperopic excimer laser refractive surgery.

METHODS: Fifteen eyes of 12 patients treated with SCTK for a corneal apical scar after hyperopic excimer laser refractive surgery were retrospectively evaluated. SCTK is a sequence of custom therapeutic excimer laser keratectomies where the results are monitored step-by-step by intraoperative corneal topography. In the preoperative and postoperative course, corrected distance visual acuity (CDVA), corneal topography and aberrometry, Scheimpflug tomography, and anterior segment optical coherence tomography were compared before and after SCTK.

RESULTS: The postoperative follow-up comprised 7 patients with 1 year and 8 patients with more than 2 years of follow-up. Functional results showed a significant increase of CDVA from 0.36 ± 0.31 to 0.14 ± 0.25 logMAR at the last available follow-up. Mean sphere did not change significantly from the baseline, demonstrating that SCTK does not induce hyperopic shift. Higher order aberrations decreased significantly from 2.57 ± 1.92 to 0.80 ± 0.42 µm at the last follow-up. Topographic indexes (irregular astigmatism index, surface asymmetry index, and surface regularity index) showed a significant improvement after SCTK. Pachymetry 3 months postoperatively showed no significant reduction during the entire follow-up in either minimum or central thickness.

CONCLUSIONS: Long-term results demonstrate that SCTK can treat this sight-threatening complication of hyperopic excimer laser refractive surgery, achieving significant improvements in visual acuity and in many corneal morphological parameters.

Corneal Apical Scar After Hyperopic Excimer Laser Refractive Surgery: Long-term Follow-up of Treatment With Sequential Customized Therapeutic Keratectomy

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Mean values of central and peripheral epithelial thickness after extreme hyperopic ablation are comparable to those of keratoconic eyes.\textsuperscript{7} It has been hypothesized that, when the epithelium reaches a thickness of approximately 20 to 25 µm, there may not be enough cells to keep it viable and epithelial breakdown may occur, possibly leading to scar formation.\textsuperscript{8} Thus, although not specifically proven, it is not unreasonable to assume that extreme hyperopic ablation, with excessive thinning of the epithelium, may, similarly to keratoconus, induce an apical syndrome.

In the past, proposed treatments included anterior lamellar keratoplasty\textsuperscript{9} and phototherapeutic keratectomy (PTK).\textsuperscript{5} However, in our experience, simple PTK is often unable to fix the problem completely and permanently. The scar may recur\textsuperscript{9} and a second surgical procedure might be necessary.

The current study evaluated the long-term results of sequential customized therapeutic keratectomy (SCTK) in highly aberrated corneas with apical scars consequent to hyperopic excimer laser refractive surgery.

**PATIENTS AND METHODS**

In this retrospective study, among the 662 SCTK cases performed between 2000 and 2015 at the Eye Center, Humanitas Clinical and Research Center (Rozzano, Italy), we included all eyes that underwent SCTK for an apical scar after hyperopic refractive surgery with a minimum 12 months of follow-up.

The inclusion criteria for SCTK were prior hyperopic excimer laser correction complicated by an apical scar with severe visual impairment, defined by a loss of at least two lines from the preoperative corrected distance visual acuity (CDVA). Exclusion criteria were: evidence of ectasia, a history of herpetic keratitis, dry eye, severe corneal infection, and concomitant ocular or systemic autoimmune disease. Other exclusion criteria were pregnancy and breastfeeding.

Informed consent was obtained accordingly from each patient, for both the treatment and use of their de-identified clinical data for publication. The institutional review board of Humanitas Clinical and Research Center ruled that approval was not required for this record review study, which was conducted according to the ethical standards set in the 1964 Declaration of Helsinki, as revised in 2000.

In the preoperative and postoperative course, the following parameters were assessed: CDVA, slit-lamp biomicroscopy, Goldmann tonometry, dilated funduscopy, corneal topography, and aberrometry for the evaluation of low and higher order aberrations (HOAs) (OPD II or III depending on the year of acquisition; Nidek, Gamagori, Japan), optical tomography and pachymetry with Pentacam (Oculus Optikgeräte GmbH, Wetzlar, Germany), and anterior segment optical coherence tomography (AS-OCT) (Cirrus HD-OCT; Carl Zeiss Meditec, Dublin, CA or XR Avanti; Optovue, Fremont, CA). Depending on the year, some data were not obtained because a particular instrument was not available (eg, AS-OCT with epithelial map).

**SCTK Procedure**

We previously introduced custom PTK with intraoperative topography\textsuperscript{8} (currently called SCTK) to treat irregular corneas that require a multistep procedure and intraoperative monitoring.

Topography, tomography, and AS-OCT (when available) were acquired on the day of surgery. The apical scar has a severe distortion effect, making Placido-based topography extremely difficult to acquire. For this reason, a drop of 0.25% hyaluronic acid masking fluid (LASERVIS; Chemedica, Munich, Germany) was instilled to improve the detection and processing of the rings.\textsuperscript{9} The patient was then asked to blink, and, if no dry areas or overfloating were detected after 5 to 10 seconds, the image was acquired.

The drop of masking fluid may slightly change the acquired curvature, but, in our opinion, it may be acceptable in the first step of the surgery where the cornea is highly aberrated and even an approximated ablation plan cannot be defined if no drops are used.

The idealized shape of a cornea with a hyperopic scar is shown in Figure 1A.

SCTK was performed with the NIDEK EC-5000 for treatments between 2000 and 2013 or with the Schwind Amaris 750 or 1050rs excimer lasers (SCHWIND eyes-tech-solutions GmbH & Co., Kleinsteinheim, Germany) for treatments between 2013 and 2016. All surgical procedures required more than one phase on the same day, as described below (see Table A and Figure A, available in the online version of this article, for a full description of the procedure):

1. Transepithelial, myopic, topography-guided ablation with a small optical zone aimed to remove the scar and part of the central HOAs.
2. Smoothing with masking fluid (wet PTK) aimed to smooth micro-irregularities.
3. Intraoperative topography, tomography, and CDVA.
4. Topography-guided hyperopic ablation with a large optical zone aimed to eliminate the abrupt change in peripheral curvature caused by the previous ablation and further reduce the remaining HOAs.
5. Smoothing with masking fluid (wet PTK) aimed to smooth micro-irregularities.
6. Intraoperative topography, tomography, and CDVA.
7. Depending on the quality of the topography data and CDVA obtained in step 6, the procedure was deemed to be complete or steps 4 to 6 were repeated (topography-guided ablation to further finalize the HOA treatment by regularizing the stromal surface).

The target for stopping the procedure was defined as follows: (1) improvement of preoperative CDVA by at least two lines, regardless of the increase or decrease of refractive error; (2) all keratoscopic rings visible without the use of masking fluid; and (3) low curvature gradient (lower than 4.00 to 5.00 D/mm) in the central 6.5 mm evaluated, when available, with the corneal curvature gradient map implemented in the CSO devices (either the EyeTop Topographer or the Sirius) or with the evaluation of the tangential map. The curvature gradient was defined as the difference between the curvatures of two points and was calculated as the first derivative of the tangential curvature map in the radial direction.

When the target was not reached, steps 4 to 7 were repeated while adhering to the conventional stromal thickness safety limit of 250 microns. We previously demonstrated the stability of the patients treated with SCTK even with low residual stromal thickness.10 Finally, a protective contact lens was placed. The time of the entire SCTK treatment varied between 10 and 20 minutes on average to a maximum of 1 hour for difficult or uncooperative patients.

Postoperatively, patients were monitored daily until total corneal re-epithelialization, and underwent complete ophthalmologic examination, with corneal topography, tomography, and AS-OCT at months 1, 3, 6, 12, 24, 36, and 48 (when available).

STATISTICAL ANALYSIS

Data are expressed as mean ± standard deviation, median and range, or number and percentage, where appropriate. The comparison of variables was performed on paired data to evaluate the improvement or relapse of individual patients over time. To assess the long-term safety and efficacy of SCTK, the preoperative values were compared with the last follow-up available for all patients. Refractive outcome differences were assessed by dioptic power matrix evaluation using the approach suggested by Kaye et al.11,12 Data are expressed, in this case, as mean refraction and 95% confidence intervals.

Differences between data were evaluated with the Wilcoxon signed-rank test. Variations of data over time are presented with box-and-whisker plots. The graphs show the distribution of variables: the box represents the 25th to 75th percentile range and the internal line represents the median. The whiskers are limited by upper and lower adjacent values. Outside the whiskers, outliers can be seen.

A P value of less than .05 was considered significant. Statistical analysis was performed using Stata 13 software (Release 13; StataCorp LP, College Station, TX). The idealization of the principal steps of the procedure was obtained by courtesy of Optimeyes Software (Optimo Medical AG, Biel, Switzerland).

RESULTS

Fifteen eyes of 12 patients (10 men, 5 women) were evaluated. The mean age of the patients was 45 ± 11 years.
The mean follow-up was 35 ± 23 months; 7 patients had 1 year of follow-up and 8 patients had more than 2 years of follow-up. No patient was lost to follow-up.

Functional and morphological results are summarized in Table 1 and Table B (available in the online version of this article).

There was a significant increase ($P < .01$) in CDVA from 0.36 ± 0.31 to 0.14 ± 0.25 logMAR (ranges in

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Clinical Outcomes of Sequential Customized Therapeutic Keratectomy for Hyperopic Scar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outcomes</td>
<td>Baseline</td>
</tr>
<tr>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td>CDVA (logMAR)</td>
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</tr>
<tr>
<td>Sph (D)</td>
<td>15</td>
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<tr>
<td>Cyl (D)</td>
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<tr>
<td>Cyl axis (degrees)</td>
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<tr>
<td>HOA RMS (µm)</td>
<td>15</td>
</tr>
<tr>
<td>Coma (µm)</td>
<td>15</td>
</tr>
<tr>
<td>ABSph (µm)</td>
<td>15</td>
</tr>
<tr>
<td>K1 (D)</td>
<td>15</td>
</tr>
<tr>
<td>K2 (D)</td>
<td>15</td>
</tr>
<tr>
<td>Kmean (D)</td>
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</tr>
<tr>
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</tr>
<tr>
<td>SAI</td>
<td>14</td>
</tr>
<tr>
<td>IAI</td>
<td>12</td>
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<tr>
<td>Minimum CCT (µm)</td>
<td>14</td>
</tr>
<tr>
<td>CCT (µm)</td>
<td>7</td>
</tr>
</tbody>
</table>

$SD = standard deviation; CDVA = corrected distance visual acuity; sph = spherical refractive error; D = dioptries; cyl = cylinder; HOA RMS = higher order aberrations root mean square; coma = comatic aberration; ABSph = spherical aberration; K1 = flat keratometry; K2 = steep keratometry; Kmean = mean keratometry; SRI = surface regularity index; SAI = surface asymmetry index; IAI = irregular astigmatism index; CCT = central corneal thickness.

**Figure 2.** Box-and-whisker plot for logMAR corrected distance visual acuity (CDVA) for baseline versus last follow-up available.

**Figure 3.** Safety standard graph showing the change in lines of corrected distance visual acuity (CDVA) following sequential customized therapeutic keratectomy.

**Table B** at the last available follow-up (Figure 2). **Figure 3** shows the safety profile of SCTK for hyperopic apical scar in terms of the change in CDVA. Sixty-seven percent of the patients gained one or more lines of CDVA, 27% had no change, and 1 case lost two lines. The latter was due to the development of a cataract at the last follow-up visit; however, in
the previous follow-up visit, the CDVA improved by one line.

The refractive outcome differences, assessed by dioptric power matrix evaluation, showed a mean difference from preoperatively to postoperatively of +0.44 +0.32 × 150 (95% confidence interval [CI] = +4.78 +2.66 × 130, -6.01 +2.20 × 35, see also Figure 4 for changes in spherical equivalent).

Comparative results of corneal HOAs showed a significant decrease in total root mean square from 2.57 ± 1.92 to 0.80 ± 0.42 µm ($P < .05$) at the last available follow-up (Figure 5). Conversely, comatic and spherical aberration did not change after SCTK ($P > .05$).

Topographic indexes that investigate corneal regularity, such as the surface asymmetry index and surface regularity index, showed a significant improvement after SCTK ($P < .05$, see Table 1, and Table A, and Figure 6).

At the 1-month follow-up visit, pachymetry showed a reduction from the baseline in minimum and central corneal thickness ($P < .05$). No significant change ($P > .05$) in either minimum or central corneal thickness was observed after 3 months, demonstrating the stability of the procedure over time.

An example of the typical outcome of SCTK in the treatment of an apical scar is shown in Figure B (available in the online version of this article). No apical scar recurrence was observed, and no patient showed signs of ectasia during the entire follow-up period. No other complications were recorded.

**DISCUSSION**

It is frequently assumed that the amount of hyperopic ablation to be achieved should be limited by calculated final corneal curvature.\textsuperscript{13} However, high post-operative curvature is not always correlated with thin epithelium, which is believed to play an important role
in the development of the scar. Indeed, it is possible to find a normal, untreated patient with steep cornea and an epithelium relatively normal in thickness, as well as a hyperopic treated patient with a normal corneal steepness but a thin epithelium.\(^3\)

This last finding suggests that a minimum preoperative epithelial thickness in addition to a high final maximum curvature gradient could be an important risk factor for apical scar development. However, it is important to exclude the presence of previous pathologies that could lead to thin epithelium such as ectasia. This hypothesis is also supported by the presence of a similar apical scar in patients with advanced keratoconus who similarly have an extremely curved cornea and exceptionally thin epithelium.\(^{14,15}\)

Therefore, in this long-term retrospective study, SCTK was performed with the described multi-step procedure with the aim of reducing HOAs and the corneal curvature gradient to prevent apical scar recurrence. Functional results showed a significant improvement in CDVA after the treatment and were stable after a minimum follow-up of 12-months, without long-term apical scar recurrence.

Moreover, our report showed that SCTK did not cause the statistically significant hyperopic shift occasionally described after PTK.\(^6\) A positive refractive shift may be caused by a plano ablation with no transition zone, particularly if the ablation diameter is small and no custom ablation is adopted. A small optical zone PTK is more likely to induce a change in refraction (hyperopic shift). This is explained by the Munnerlyn formula, which postulates: \(t = \frac{S^2 \times D}{3}\), where \(t\) = thickness of the ablated tissue in microns, \(S\) = diameter of the optical zone in millimeters, and \(D\) = dioptric correction.

If we solve the equation for dioptric correction, the formula clearly shows that, if we increase the diameter and leave the ablation depth unchanged, the amount of dioptric correction will decrease by the square of the optical zone: \(D = \frac{t \times 3}{S^2}\). Even with clear limitations, the Munnerlyn formula is able to explain the importance of a large optical zone when doing PTK. However, the non-significant refractive shift does not necessarily mean that SCTK in hyperopic ablation is completely refractively neutral, as proved by the range of observed refractive changes. Furthermore, SCTK in hyperopic scar corneas is absolutely not a refractive procedure. These patients have irregular corneas and the first goal is to increase their vision, regardless of refraction. We therefore consider refraction to be a secondary outcome.

Our study showed that SCTK was able to induce a significant reduction in HOAs together with topographic indexes that evaluate corneal regularity. This last finding proves that, once the corneal curvature gradient has decreased and the apical scar is resolved, morphological and functional indexes improve synchronously. Moreover, a reduction of HOAs, which should be a primary aim of therapeutic treatment, induced not only an increase in the quantity of vision (shown by the increase of visual acuity), but also an improvement in quality (shown indirectly by the decrease in corneal aberrations). However, we observed a non-significant decrease in coma- and spherical aberration-like HOAs and a significant decrease in root mean square values.

We hypothesize that this might be explained by the irregularity induced by the hyperopic scar (clearly visible in the keratoscopy: all rings appear merged together and those highly irregular areas are completely unprocessed and then not taken into account. Perhaps, due to this high focal irregularity, Fourier analysis is not able to differentiate between coma- and spherical aberration-like HOAs and puts everything together in root mean square, making it high. Moreover, almost all hyperopic patients present with a high angle \(K\). Therefore, if the refractive spherical treatment is tracked on the pupil center and not on the visual axis, coma may be induced.

Initially, during re-treatment, opacity makes it difficult to properly track the visual axis, thus explaining the lack of improvement. After surgery, when the cornea is more regular, Fourier analysis is more reliable and decomposition is then able to differentiate between the aberrations.

To our knowledge, this is the first study on a sequential therapeutic excimer laser refractive procedure for the correction of an apical scar induced by hyperopic refractive ablation. The choice of sequential treatment with repeated intraoperative topography is of paramount importance because a one-step procedure currently appears to be unfeasible and other treatments should be required. In particular, a single ablation would lead to unpredictable results due to two main issues. First, there is always a difference in ablation rate between the stroma (softer) and scar (harder). Second, the shape of the cornea measured by tomography/topography does not perfectly match the stromal shape. This is due to either dissimilar thickness of the epithelium between the center and the periphery or possible approximation of the corneal shape due to the use of masking fluid, at times a necessity to acquire keratoscopy.

The customized approach provides focal treatment of irregular corneal areas, rather than a uniform treatment like that of a plano PTK. Moreover, in these corneas, the scar is frequently not at the center of the cornea because the initial hyperopic ablation was shifted.
nasally to take into account the commonly high angle kappa observed in hyperopic patients.\textsuperscript{17} Indeed, the scar will form in the point of the highest curvature gradient (the apex), where the ablation was centered. It is then of foremost importance to slightly increase ablation in that particular point. This can be easily achieved by topography-guided ablation.

When dealing with irregular corneas like those described in our study, topography-guided ablation is preferable to wavefront-guided ablation for several reasons. First, total aberrometric measurement is performed through a limited pupillary diameter with lower resolution than topography. Thus, optimization of the corneal surface through this approach leaves large portions of peripheral cornea and their irregularities untouched, with consequent incomplete treatment and possible regression. Additionally, when substantial stromal opacities are present, aberrometry becomes totally unreliable. Moreover, wavefront-guided ablations try to correct all aberrations regardless of their origin, whether in the posterior cornea, lens, or retinal surface. Conversely, the only aim of these therapeutic treatments (SCTK or PTK in general) is to correct the aberrations caused by refractive treatment impairing the anterior surface.

Few options were available in the past for the treatment of an apical scar after hyperopic ablation. Anterior lamellar keratoplasty with a microkeratome\textsuperscript{8} was a feasible option but entailed the use of donor tissue with all of the complications related to a lamellar graft. Similarly, plano PTK was tried, without promising results.\textsuperscript{5} Indeed, neither technique can remove the apical scar locally or decrease the corneal curvature gradient, which is the plausible cause of the scar and its recurrence.

Another interesting option, although not yet published, is transepithelial PTK, also programmed according to the VHF Digital Ultrasound Epithelial Thickness Profiles or OCT-measured depth of the scarring and epithelium. Transepithelial PTK uses the epithelium as a natural masking agent to focus the ablation onto the relatively elevated region of the stroma, where the epithelium is thinnest (ie, the location of an apical scar after hyperopic correction). An ablation of 50 to 60 µm (the normal epithelial thickness) would probably improve the shape and, subsequently, the vision of the patient. Still, based on our experience, transepithelial PTK would not be able to fix the problem completely in a single-day treatment. Additionally, with intraoperative topographies, it is possible to evaluate the final shape of the cornea and avoid a high corneal curvature gradient, which may cause recurrence of epithelial thinning and, possibly, of an apical scar.\textsuperscript{2,15}

Furthermore, the published outcome of transepithelial PTK shows that the refractive shift is currently unpredictable, as demonstrated by the population results reported by Reinstein et al.\textsuperscript{16}; a myopic shift was equally as likely as a hyperopic shift and the change in spherical equivalent refraction was within ±0.50 D in only 41% of cases after a transepithelial PTK alone.

Applying a flat-depth transepithelial PTK, considered as equal depths at all ablation positions, induces a hyperopic shift. First, the axial length of the eye is slightly reduced following the removal of corneal tissue, inducing minor hyperopia (< 0.25 D per 100 µm of PTK).\textsuperscript{19} Second, during PTK central epithelium (thinner in general and much more after hyperopic scarring) would be ablated before completing the peripheral epithelium (thicker). The following ablation, aimed to fully ablate peripheral epithelium, would remove roughly 10 µm of the central stroma, resembling a -0.75 D myopic correction (ie, inducing ±0.75 D hyperopic shift [±0.15 D from 65 µm shortened axial length, so approximately a total 0.90 D of hyperopic shift]).\textsuperscript{20} Third, a laser without radial energy compensation features a different central to peripheral ablation rate and may therefore worsen the problem. This effect can also be calculated but is system dependent.\textsuperscript{21} As a gross rule-of-thumb, loss of efficiency may account for approximately 40% of the effect, which means that a further 0.60 D hyperopic shift can be estimated from loss of efficiency, adding up to a total of ±1.50 D of hyperopic shift.

A swept-source OCT-based ablation that takes into account the stromal and epithelial profile would also be highly desirable and could solve these complications more easily. Unfortunately, to our knowledge, there is no custom ablation software able to use such a device to plan ablations.

The limitations of this study are the relatively small number of patients, the different lasers and measurement instruments used, and the lack of comparison with other standard techniques such as plano PTK or transplants. Regarding the first limitation, even though 15 eyes is not a large group, it should be considered that this pathology is uncommon, and we included only patients with a follow-up of at least 12 months. We deliberately included the outcomes of more than one laser because we wanted to prove that the treatment is feasible even with different platforms. This data set testifies to our experience over 16 years. We obviously noted a better performance with the newer lasers, but the small number of patients in each group did not allow a statistical evaluation of the difference. More studies might be needed for a prospective comparison of the outcome of SCTK and other procedures. Another limitation is the lack of comparison between the preoperative and postoperative corneal curvature...
gradient due to the long follow-up period and incompleteness of preoperative examinations in the past. This comparison is currently the subject of an ongoing study.

A prospective study, currently in progress, is also evaluating the outcomes of the treatment of hyperopic scar, taking into account epithelial maps, the use of customized optical zones, and the number of diopters treated in each step of SCTK. However, given the infrequency of this complication with the new laser profiles, we did not have enough patients with long-term follow-up to be included in this study.

Our long-term study demonstrates that it is possible to achieve a safe and effective treatment of this rare and severe complication, even after years of follow-up. Based on our experience, we suggest avoiding more invasive or older procedures for the management of an apical scar after hyperopic ablation, such as corneal transplant or plano PTK, and try SCTK to prevent serious complications.

**AUTHOR CONTRIBUTIONS**

Study concept and design (PV, RV); data collection (LP, ST, RV); analysis and interpretation of data (PV, FIC, EM, CA, RV); writing the manuscript (FIC, LP, RV); critical revision of the manuscript (PV, FIC, EM, CA, ST, RV); supervision (PV)

**REFERENCES**

TABLE A

Description of Sequential Customized Therapeutic Keratectomy

**Phase 1: Transepithelial, Myopic, Topography-Guided Ablation.** The first phase of the procedure includes transepithelial, myopic, topography-guided ablation with a small optical zone (normally between -3.00 and -4.50 diopters [D] with a 3-mm optical zone), without a transition zone, to flatten the central cornea (the idealized postoperative shape is shown in Figure 1B). The myopic correction and optical zone were decided based on the elevation of the scar from the surrounding stroma and the preoperative corneal curvature gradient.

In some laser platforms, it is possible to select which significant higher order aberrations (HOAs) should be treated as a priority, ignoring all others to minimize ablation depth or volume.

This ablation mainly aims to remove the steep scar and regularize the cornea because the scar is frequently not in the center, thanks to the customized treatment. The ablation is not expected to induce a refraction change because, although the scar optically influences the quality of vision, it does not significantly alter the mean corneal curvature. As a matter of fact, these patients, despite a steep scar in the middle of the pupillary field, often display a plano or slightly hyperopic refraction. Moreover, as shown in Figure A, ablation removes only the scar centrally and in the 2 mm around it, where the epithelium is thick (eg, around a keratoconic ectasia). Normally, ablation does not even reach the level of the surrounding stromal surface. After ablation, the remaining epithelium in the periphery is removed manually.

**Phase 2: Smoothing With Masking Fluid (Wet Phototherapeutic Keratectomy [PTK]).** After ablation, smoothing was performed to remove corneal micro-irregularities even smaller than the spot size and achieve a regular stromal bed as similar as possible to the physiological Bowman’s layer. A drop of hyaluronic acid masking fluid (LASERVIS, Chemedica, Munich, Germany) was applied to the cornea. A planar PTK ablation was applied with a diameter of 10 mm and depth of 20 µm, thus covering the entire corneal diameter and minimizing any potential hyperopic shift. The masking fluid is continuously distributed over the corneal surface during ablation using a spatula (eg, Buratto’s spatula; ASICO, Westmont, IL). The masking fluid is added and evenly distributed with the spatula to maintain a thin layer of fluid and avoid the formation of dry areas.

This masking fluid has the same ablation rate as the stromal tissue. For this reason, most of the ablation is done on the fluid and a minimal amount of the small irregularities of the stroma (“peaks” emerging from the fluid layer). As it was previously described, because of the protective action of the masking fluid, the actual ablation is only a few microns.

**Phase 3: Intraoperative Topography, Tomography, and Corrected Distance Visual Acuity (CDVA).** After this treatment, the patient was taken to a nearby examining room and intraoperative topography, tomography, and CDVA were performed to monitor the effectiveness of the procedure to this point. All intraoperative corneal measurements were acquired with the Sirius or EyeTop Topographer (Costruzione Strumenti Oftalmici [CSO], Florence, Italy), depending on the year of surgery.

To obtain a reliable measurement, keratoscopy was performed after irrigation with balanced salt solution and one drop of masking fluid (LASERVIS). We previously published that intraoperative, epithelium-free topography-based corneal aberrometry is a feasible option for custom ablation in highly aberrated eyes. Even if corneal edema might occur, because it is diffused, it is not expected to change the overall shape of the cornea, but only its thickness.

**Phase 4: Topography-Guided Hyperopic Ablation With a Large Optical Zone.** The next step of the procedure involved intraoperative topography-guided ablation with the largest possible optical zone available (eg, 8.5-mm optical zone with transition zone up to 10 mm) and slight hyperopic correction ranging from +1.00 to (rarely) +3.00 D. This was done with the goal of eliminating the abrupt change in peripheral curvature caused by the previous ablation (Figure 1C: idealized post-ablation shape) and the remaining HOAs. Correction of astigmatism, when present, was a secondary goal. The decision process for choosing the hyperopic ablation power was based on the appearance of the cornea and the experience of the surgeon. A higher hyperopic correction was planned when the curvature change in the paracentral cornea induced by the small zone myopic ablation performed in Phase 1 was more abrupt. This was assessed by the rate of corneal curvature gradient, the intensity of the red ring visible in the instantaneous topography maps, and the amount of positive spherical aberration.

**Phases 5 to 7: Wet PTK, Intraoperative Evaluation, and Decision Whether to Stop or Continue.** As after the first ablation, another wet PTK smoothing ablation was performed. The patient was then taken back to a nearby examining room to again assess the CDVA and obtain an intraoperative topography measurement, to define the progress of the procedure. As before, a drop of masking fluid was applied prior to acquiring the topography scan and assessment of visual acuity.

The surgeon could then decide whether to stop the procedure or to perform another topography-guided ablation to further regularize the cornea based on these intraoperative measurements.
### TABLE B
Range Values for Clinical Outcomes of Sequential Customized Therapeutic Keratectomy for Hyperopic Scar

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Baseline</th>
<th></th>
<th>Follow-up</th>
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<tr>
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<td>Min</td>
<td>Max</td>
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<td>2.18</td>
<td>0.038</td>
<td>1.42</td>
</tr>
<tr>
<td>K1 (D)</td>
<td>43.1</td>
<td>53.00</td>
<td>36.70</td>
<td>47.60</td>
</tr>
<tr>
<td>K2 (D)</td>
<td>39.0</td>
<td>49.10</td>
<td>36.30</td>
<td>45.50</td>
</tr>
<tr>
<td>Kmean (D)</td>
<td>40.90</td>
<td>50.90</td>
<td>35.10</td>
<td>46.13</td>
</tr>
<tr>
<td>SRI</td>
<td>0.8</td>
<td>2.3</td>
<td>0.32</td>
<td>1.93</td>
</tr>
<tr>
<td>SAI</td>
<td>0.62</td>
<td>5.48</td>
<td>0.36</td>
<td>2.13</td>
</tr>
<tr>
<td>IAI</td>
<td>0.51</td>
<td>0.85</td>
<td>0.44</td>
<td>0.69</td>
</tr>
<tr>
<td>Minimum CCT (µm)</td>
<td>261</td>
<td>577</td>
<td>363</td>
<td>529</td>
</tr>
<tr>
<td>CCT (µm)</td>
<td>484</td>
<td>613</td>
<td>370</td>
<td>534</td>
</tr>
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*CDVA = corrected distance visual acuity; sph = spherical refractive error; D = diopters; cyl = cylinder; HOA RMS = higher order aberrations root mean square; coma = comatic aberration; ABSph = spherical aberration; K1 = flat keratometry; K2 = steep keratometry; Kmean = mean keratometry; SRI = surface regularity index; SAI = surface asymmetry index; IAI = irregular astigmatism index; CCT = central corneal thickness*
A 37-year-old man underwent hyperopic photorefractive keratectomy (unknown preoperative refraction but more than 6.00 diopters) in both eyes in another center in 2003. Ten years later, he presented with a dense hyperopic scar. The (A) preoperative thickness and (B) instantaneous map. The hyperopic scar is clearly visible in the Scheimpflug image (center). Corrected distance visual acuity (CDVA) was 20/20 with a refraction of +5.00 -3.50 × 10. A sequential customized therapeutic keratectomy was then proposed and performed. The (C) 12-month postoperative pachymetry and (D) instantaneous map. CDVA increased to 20/20 as the corneal shape normalized, becoming prolate and regular. (E) The differential instantaneous map before and after sequential customized therapeutic keratectomy. (F) The differential pachymetry map highlighting where tissue was ablated. No apical scar recurrence was observed, and no patient showed signs of ectasia during the entire follow-up period. No other complications were recorded.